

8532 ANALYSIS
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B Of a COURSE of
LECTURES
ON

MECHANICS, PNEUMATICS,
HYDROSTATICS, || ELECTRICITY, and
HYDRAULICS, || ASTRONOMY.

READ BY

JAMES FERGUSON, F.R.S.

The EIGHTH EDITION.

Nil tam difficile est quod non solertia vincat.

Gul. Lil. Mon. Pæd.



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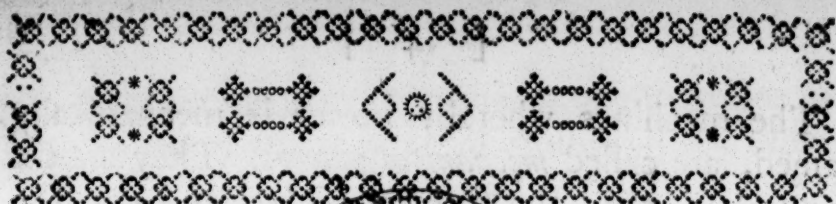
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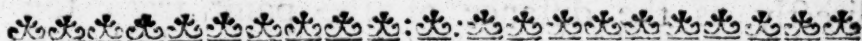
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A N A L Y S I S

Of a COURSE of

L E C T U R E S.



L E C T U R E I.

On MECHANICS.



WHEN two bodies are suspended upon any machine or engine, so as to act against one another, if the engine be put into motion, and the lightest body moves through as much more space than the heaviest, as the weight of the heaviest exceeds the weight of the lightest, the bodies will balance or support each other.

Upon this principle, the force, power, or advantage of any machine, whether simple or compound, is easily computed: for it is always as great as the velocity of the power applied to work the machine exceeds the velocity of the weight to be raised, or the resistance to be overcome: proper allowance being made for friction.

The machines whereby power is mechanically gained, are called *mechanical powers*. They are fix in number, *viz.* the *lever*, the *wheel and axle*, the *pulley*, or rather system of pullies, the *inclined plane*, the *wedge*, and the *screw*. — Of these, all sorts of mechanical engines do consist: and in treating of them, so as to settle their theory, we consider them as mathematically exact and perfect, and moving without friction.

A *lever* is a bar, turning upon a prop, or center of motion; and is used either to raise weights, or overcome resistances. — When the lever is put into motion, the velocity of each point of it is directly as the distance of the point from the prop. The two parts of the lever, which are on the opposite sides of the prop, are called the *arms of the lever*; and a man can raise as much more weight by this machine, than he could do by his natural strength without it, as the length of the arm to which he applies his power of force, exceeds the length of the other arm which is applied to raise the weight.

In the *wheel and axle*, where the power is applied to the wheel, and the weight is raised by a rope winding round the axle, the velocity of the power is to the velocity of the weight as the circumference of the wheel is to the circumference of the axle: and the power or advantage gained by this machine is in the same proportion.

A single *pulley* that only turns on its axis, and does not rise with the weight, serves only to change the direction of the power: for it gives no mechanical advantage to the power.

When, besides the upper pullies which turn round in a fixed block, there is a block of pullies which rise equally with the weight; the velocity
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of the weight is to the velocity of the power as one is to twice the number of pulleys in the moveable block : and the power and weight balance each other, when the power is in proportion to the weight as one is to twice the number of pulleys in the moveable block.

A weight raised, or resistance overcome, by an *inclined plane*, moves only through a space equal to the height or thickness of the plane in the time that the power drives the plane through a space equal to its whole length. Hence, the velocity of the power is in proportion to the velocity of the weight, as the length of the plane is to its thickness or height; and the power and weight balance each other when the power is to the weight as the thickness of the plane is to its length.

A *wedge*, in the common form, is like two inclined planes joined together at their bases, and the thickness of these planes make the back or top of the wedge, to which the power is applied in cleaving of wood.

When two equal resistances act perpendicularly against opposite sides of the wedge, and a power acts perpendicularly against the top of the wedge, the velocity of the power is in proportion to the velocity of the resistance on either side of the wedge, as the length of either of its sides is to half the thickness of its top : and the power balances the resistance of the wood, when the power is in proportion to the resistance as half the thickness of the wedge at its top is to the length of either of its sides, if the sharp edge goes to the bottom of the cleft in the wood. But, when the wood splits before the wedge, as it generally does, the power and resistance balance each other, when the power is to the resistance as half the thickness of

of

of the top of the wedge (when it is driven quite into the wood) is to the whole length of the clift below the top of the wedge.

In the *screw*, the velocity of the power is in proportion to the velocity of the weight raised, or resistance overcome, as the circumference of a circle described by the power in one turn of the screw is to the distance between the spirals of the screw: and the power and resistance balance each other, when the former is to the latter as the distance between the spirals is to the circumference of the circle described by the power, which is generally applied to the end of a lever or bar, put through the shank of the screw.

In raising weights by all sorts of machines or engines, the time that is lost in working them is as much as the power gained by them. That is, if a man can raise an hundred weight by his natural strength, to any given height, and has forty hundred weight to raise to the same height by a machine to which he applies his natural strength or power; he will be forty times as long in raising the weight by the machine as he would be in raising a fortieth part of it by his own strength without any machine at all.

In raising a weight by any machine or engine, as much more power must be applied than that which is sufficient to balance the weight, as the friction of the machine amounts to.

If machines could be made without friction, the least degree of power added to that which balances the weight, would be sufficient to raise it. In the lever, the friction is next to nothing; in the wheel and axle it is but small; in the pulleys it is very considerable; and in the inclined plane, wedge, and screw, it is very great.

Cranes,

Cranes, for raising great weights, consist of trundles, wheels, axles, pullies, a gib, a handle or winch, and a catch or stop to prevent the running down of the weight, if the workers of the crane should happen inadvertently to quite their hold of the winch.— The great crane at *Bristol* is reckoned to be the best and safest one in Europe.

Pyrometers are machines for measuring the degrees of expansion of metals by heat. They are made of various forms, which cannot be described here. The one which is used in these lectures shews the expansion of metals to the 90,000th part of an inch.



LECTURE II.

On MECHANICS.

THE *center of gravity* of a body is a point, round which all the parts of the body balance each other; and the body descends by its own weight in the same manner that it would do if its whole weight were accumulated in that point. Therefore, the weight of a body will cause it to fall, if its center of gravity be not supported.

If a perpendicular, let fall from the center of gravity, falls within the base, or part of the ground on which the body is placed, the body will stand; otherwise, it will tumble or fall.

A *cylinder* is supported on an inclined plane, by a power which is in proportion to the weight of the cylinder, as the height or thickness of the plane is to the length of the plane. If the power be less, the cylinder will run down the plane; if greater, it will be drawn up. Hence, when the weight of
a loaded

a loaded *cart* or *waggon*, and the angle of the hill's height, are known, the power required to support the load on the hill may be found. And if the power be increased, so as to overcome the friction of the axles of the wheels, the load will be drawn up.

Thus, supposing the side of the hill to be a smooth plane, and the angle of its height to be 7 degrees 14 minutes*, the perpendicular height of the hill is, in that case, equal to the eighth part of the length of its side; and the power that balances the load thereon is equal to an eighth part of the weight of the load.

If the angle of the height be 14 degrees 21 minutes, the height of the hill is equal to a fourth part of the length of its side; and a power equal to a fourth part of the load will balance it.

If the angle of height be 22 degrees 2 minutes, the height of the hill is equal to three eighth parts of the length of its side; and a power equal to three eighth parts of the load will balance it.

If the angle of height be 30 degrees, the height of the hill is equal to half the length of its side: but this would be rather too steep for any cart or waggon; because the horses would have great difficulty in fixing their feet in the ground. — Whenever this happens, if a man would get upon the back of each horse, their weight would be increased, and the horses could fix their feet so much the better, which would not diminish their power of drawing.

It is proved by two models of carts, one of which has its wheels twice as big as those of the other, that when they are loaded with equal weights,

* A minute, in this sense, is the 60th part of a degree.

it requires twice as much power to draw the cart which has the smaller wheels, as to draw the other whose wheels are twice as big.

It is also proved, by two models of waggons, one of which has broad wheels and the other narrow ones, that broad wheels are just as easily drawn on plain hard ground as narrow ones; and easier on sandy or rough ground, because they sink not so deep into the earth. — It is also plain by experiment, that whether the wheels be broad or narrow, the waggon is much easier drawn either on rough or smooth ground, when the heaviest part of the load is put over the axle of the hind wheels, which are the biggest, than when it is put over the axle of the small fore-wheels.

In *water-mills*, the velocity of the float-boards of a *breast wheel*, or buckets of an *overshot wheel*, ought to be equal to a third part of the velocity of the water where it turns the wheel; and the train should be such, that the grinding stone may make about 60 revolutions in a minute.

The number of rounds, or upright staves in the trundle, should be no aliquot part of the number of cogs in the wheel that turns the trundle; for, when they are not, each cog will fall upon a different staff from what it did last before: and, by that means, they will all wear more equally than if it took the same staff in each revolution.

In *mills for sawing timber*, either by means of wind or water, the saws are moved up and down by cranks on the axle of a trundle turned by a wheel; and the timber is gradually drawn forward to the saws by the slow motions of wheels, which are pulled round, tooth after tooth, by hooks in levers moved up and down by the saws.

It is proved by experiments, that the *power of the wind*, on wind-mill sails, is as the *square of the velocity of the wind*: that is, four times as great when the velocity of the wind is double; nine times as great when the velocity is triple; sixteen times as great when the velocity is quadruple; and so on.

When the wind blows but one mile in an hour, we can hardly say that *we feel it*: when it blows or moves from two to three miles in an hour, it is *just perceptible*: from four to five miles in one hour, we call it a *gentle pleasant wind*: from 10 to 15 miles, a *pleasant brisk gale*: from 20 to 25 miles, *very brisk*: from 30 to 35 miles in an hour, *high wind*: from 40 to 45 miles, *very high*: at 50 miles, a *storm or tempest*: at 60 miles, a *great storm*: at 80 miles, a *hurricane*: and, at 100 miles in an hour, a *hurricane that tears up trees and carries buildings*, &c. before it.

The *engine* by which the *piles* were driven at Westminster-Bridge was so contrived, that when the horses that turned it went constantly round the great shaft, a weight was drawn up to a great height, then let fall freely upon the top of the pile, and was immediately followed by a pair of tongs which took hold of the weight and drew it up again. A large fly regulated the motion, and acted against the horses to keep them from falling forward when the weight dropt. The tongs were nearly counterpoised by another weight, whose small rope wound upon a spiral fusy, so as to cause the tongs to fall with a moderate and uniform velocity.

LECTURE III.

On HYDROSTATICS.

FLUIDS press equally in all manner of directions, as is shewn by their rising in four glass tubes open at each end; one tube being quite straight, another bent directly upward at the lower end, a third bent sideways to a right angle, and a fourth bent obliquely. All these tubes being put into water, almost to their tops, the water rises in each of them to a level with the surface of the water in which they are immersed.

If an empty phial, heavy enough to sink in water, be corked, and suspended by a thread at one end of a balance, then immersed in water and counterpoised by weights in a scale at the other end of the beam, upon pulling out the cork, and letting the phial fill with water, it will descend; and will then require as much additional weight put into the scale, to counterbalance the phial, as will weigh all the water in air that filled it up to the cork. This shews, that fluids weigh as much in their own elements as they weigh in air.

If a piece of lead, whose upper side is flat, be put into an empty vessel; and a piece of wood, whose under side is flat, be laid upon the lead, so as no water may get in between them; and the wood be held down till the vessel be filled with water; the wood will remain upon the lead at bottom: for it is then kept down, both by its own weight, and the weight of the water above it: the upward pressure of the water being prevented, because none gets in between the lead and the wood.

If a wide tube, open at both ends, has a piece of lead held close to its lower end, by a string within the tube, so as no water can get in between the lead and the tube; and then, if the whole be immersed in water, till the depth of the lead below the surface of the water in the vessel be almost twelve times the thickness of the lead; the string may then be let go: for the lead will not fall away from the tube, because the upward pressure of the water, at that depth, is greater than the weight of the lead, and no water gets above it to press it down. — But if the tube and lead be drawn up, till the depression of the lead below the surface of the water in the vessel is any thing less than $11 \frac{1}{2}$ times the thickness of the lead, it will then fall off; which shews, that lead is $11 \frac{1}{2}$ times as heavy as its bulk of water.

If a tube, three or four inches wide, and open at both ends, has a wet bladder tied over one end, so as the bladder may be flaccid, and some water be then poured into the tube, it will press the bladder downward, and make it concave within, below the tube. But, if that end be immersed in a vessel of water, till the surface of the water within the tube be even with the surface of the water in the vessel without it, the bladder will then be flatish, as if it were not pressed at all, because it is equally pressed on both sides. If it be plunged deeper, the bladder will be pressed upwards, so as to be convex within the tube: if it be raised higher, it will be more pressed downward than upward, and be concave within. This shews, that the pressure of fluids depends upon their height, without any regard to their quantity.

If a small tube be joined to a very large one, and the whole be bent in the middle, so as the two parts may

may be parallel, or make any angle; water may be poured into either tube, and it will rise just as high in the other, and settle in both, with surfaces parallel to the horizon, when you leave off pouring; even tho' one tube should contain ten thousand times as much as the other; this shews, that the smallest quantity of a fluid will balance the greatest quantity whatever, at equal heights, if they join at bottom: and that water in pipes will ascend to the level of the spring from whence it came.

If a small tube, about two feet long, and open throughout, has one end bent to a right angle, and the open neck of a bladder be tied round that end; if then the bladder be put into a box, and have a board put upon it with twenty pounds weight laid upon the board, and the tube be held upright, and water be poured into it, the water will run into the bladder, and raise all the weight. And, by the time that the water stands about 20 inches high in the tube, it will support the weight, although the bore of the tube were so small as not to contain an ounce of water.

Let a piece of light wood be put into one scale of a common balance, and as much water be put into the other scale as will counterbalance the wood; then, let the wood be taken out of the scale, and put into a glass brim full of water; the wood will cause as much water to run over the brim as is equal in bulk to that part of the wood which goes below the surface of the water. Then, take the wood out of the glass, and pour in the water from the scale that balanced the weight of the wood; and it will fill the glass up to the brim again. This proves, that a quantity of water equal in bulk to the immersed part of the wood, is just

as heavy as the whole of the wood ; and consequently, that the quantity of water displaced by a ship, is equal to the whole weight of the ship and her cargo.

The pressure of a fluid, upon the bottoms of all vessels whatever, is proportional to their bases and perpendicular heights, without any regard to the quantities they contain. — This is shewn by two vessels of equal bases and heights, but of very different capacities, their bottoms being kept up by equal forces ; for, at whatever height the water is in one vessel when it presseth off the bottom, it does the like when poured in to the same height in the other.

A *siphon* will not run, unless the perpendicular height of the column of fluid in the outer leg be greater than the perpendicular height of the column in the inner leg above the surface of the fluid in the vessel in which that leg is partly immersed.

By the *Tantalus Cup*, and two other machines, the causes of the ebbing and flowing of wells, and of intermitting and reciprocating springs, are explained.

LECTURE IV.

On SPECIFIC GRAVITIES and HYDRAULIC ENGINES.

A Body lighter than its bulk of a fluid, will swim therein ; if heavier, it will sink : if of equal weight, it will rest any where between the top and bottom of the fluid.

If a solid body, heavier than its bulk of a fluid, be immersed and suspended therein, it will lose as much

much of its weight as its bulk of the fluid weighs: but the weight lost by the solid, will be imparted to the fluid. Hence, all equal bodies, immersed and suspended in fluids, will lose equal weights therein; and unequal bodies will lose weights proportionable to their bulks.

If the weight of a body in air be divided by what it loses in a fluid, the quotient will shew how much heavier it is than its bulk of that fluid, or its specific gravity.

By this trial, pure gold is found to be 19.640 times as heavy as its bulk of water: Guinea gold 17.200 times as heavy: quicksilver 13.575 times: lead 11.325 times: standard silver 10.535: copper 9.000: plate brass 8.000: steel 7.809: and iron 7.907. — A cubic foot of common water weighs 1000 avoirdupoise ounces: and if the decimal points be taken away from the above numbers, and they be reckoned to be whole, they will shew how many avoirdupoise ounces are contained in a cubic foot in each of the above mentioned bodies. Thus a cubic foot of pure gold weighs 19640 ounces; a cubic foot of Guinea gold 17200; and so on.

A cubic inch of brass, or any other metal, loses $253\frac{1}{2}$ grains of its aerial weight in water; in proof spirits it loses 235 grains. Hence, a cubic inch of water weighs $253\frac{1}{2}$ grains, and a cubic inch of proof spirit 235.

In a *common pump*, as the piston is raised above what is called the sucking valve, the water rises by the pressure of the atmosphere to the height of about 32 feet, in that part of the pump out of which the air is taken by the piston. Therefore, the piston (or bucket) must always work within 32 feet of the surface of the water in the well; other-

otherwise, the water will never get above it. But, at any distance, less than 32 feet from the surface of the well, the water will rise above the bucket, and then it may be lifted to any height whatever, by applying a sufficient quantity of power to the handle.

In a *forcing pump*, the water rises above the sucking valve by the pressure of the atmosphere, as in the common pump. But, instead of a bucket with a valve in it, there is a solid plunger, that fits the pump-bore so, as neither water nor air can get between. The plunger, in descending, forces the water through a side pipe into an air vessel, through a valve therein; and a pipe is fixed into the top of the air vessel, and comes down almost to reach the valve. As the water is forced into this vessel, above the end of the pipe, it compresses the air within; and the force of the compressed air, acting on the water, drives it out of the air vessel, up the pipe; the height of which must be in proportion to the degree of power applied to the handle of the pump.

On this principle, *engines* are made for *extinguishing fire*, and for raising water to gentlemen's seats which are above the level of rivers or springs. — If such an engine has a quadruple crank, for working four forcing pumps, by means of a wheel turned by water, or by horses, and all the pumps throwing the water into one common pipe, the water may be forced up to any given height answerable to the power that turns the wheel.

A wheel, that is turned by water, may have buckets hung to its ring, all around. As the buckets dip into the water, each will bring up as much as fills it, to the top of the wheel; and at that height, the water may be thrown into a cistern, and conveyed from thence in pipes. *The*

The great engine at London-Bridge, for raising water to supply the city, consists of a large water-wheel, on the axis of which are two wheels with spur cogs, each turning a trundle which has four cranks on its axis, moving so many levers up and down; and each lever works a forcing pump, by moving its plunger up and down in the pump barrel.

There is a hill near one of the *Hungarian* mines, having a fine spring 145 feet above the plain surface of the ground. The water is let down from this spring into a close vessel standing on the surface of the ground; and a small air-pipe goes from that vessel down to another vessel at the bottom of the mine; and a pipe goes from that last vessel up to the surface of the ground. — The water that runs down into the former vessel forces the air out of it, down into the vessel in the mine; and the air, being compressed on the water which is let into that vessel from the mine, drives the water out of that vessel, up through the pipe, which is 104 feet high, to the surface of the ground, where the water runs off; and, by this means, the water is raised from the mine. — There are several cocks in this engine, which are opened and shut occasionally, by men who attend for that purpose.

Mr. Blakey's fire engine acts upon this principle: only he compresses the air by steam from a boiler, which is placed above ground. The air, thus compressed in a close vessel, is forced down a pipe, into a vessel filled with water in the bottom of the mine: and the force of the compressed air drives the water out of that vessel, up through a pipe, to the surface of the ground. And thus, by the opening and shutting of some cocks, the vessel in the mine is emptied at each stroke.

 LECTURE V.
 On PNEUMATICS.

THE principal parts of the *air-pump* are so much like those of the water-pump, that whoever understands the one will be at no loss to understand the other. The use of this engine is to exhaust the air out of glass vessels, generally called *receivers*.

If a glass of water be placed under a receiver which has a round hole at top, and a piece of wood be cemented in that hole, and the lower end of the wood go down into the water, and the top of the wood be about an inch above the receiver; let the top be covered by one's thumb, and the receiver exhausted of air; then if the thumb be taken off, the air will rush into the water under the receiver, and make a great bubbling therein. But, cover the top of the wood again, and the bubbling will cease. — This shews, that no air can pass through the lateral pores of the wood into the longitudinal pores thereof.

A bell will not ring, although the clapper strikes, under an exhausted receiver; which shews, that there can be no sound without air.

In a tall receiver, exhausted of air, the down of a feather will fall as soon from the top to the bottom, as a guinea will: which shews that all bodies fall equally quick *in vacuo*.

A vessel that holds two quarts, is found to be 32 grains lighter when the air is exhausted out of it, than it was when full of air. — This shews, that a
 quart

quart of air (in English wine measure) weighs 16 grains.

If a person puts his hand on the top of an open receiver, which is about 2 inches wide, and the air be exhausted out of the receiver, his hand will be held down so fast by the pressure of the atmosphere, that he cannot get it off until the air be let into the receiver again.

The weight of the air breaks a bladder, tied over the top of an open receiver, when the air is exhausted out of it.

If one end of a bit of dry hasel branch be fixed into a hole in the bottom of a cup, and the other end into a hole the top of the receiver, and some quicksilver be poured into the cup; if then the receiver be exhausted of air, the pressure of the atmosphere will force the quicksilver down through the pores of the wood into the receiver.

If a glass tube, about 32 inches long, and open at one end, be filled with quicksilver, and the open end placed in a jar of quicksilver, and the whole covered with a tall receiver; the pressure of the atmosphere on the quicksilver in the jar will keep it up in the tube, as high as it then stands in the barometer. But, if the receiver be exhausted of air, all the quicksilver will descend out of the tube into the jar; and, upon letting the air into the receiver again, its pressure will force the quicksilver up into the tube again, as high as it was before; which shews, that the quicksilver in the barometer is kept up by the pressure of the air.

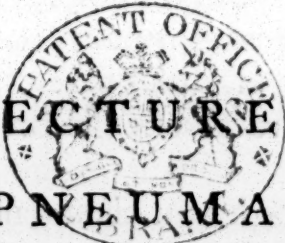
If a pump be placed in water, under a receiver, and the air be exhausted, no water can be raised by working the piston, until the air be let in again: which shews, that the water rises in pumps

by the pressure of the air, and not by any such thing as suction.

And, by an experiment with two receivers one placed under the other, it is proved to a demonstration, that the receivers are held down on the pump-plate by the pressure of the atmosphere; not by suction of the pump.

If a pipe be fixed into a plate which covers the open end of a tall receiver, and the air be exhausted; if then the pipe be put into a basin of water, the pressure of the air will force the water upward, so as to make a fountain in the exhausted receiver.

If the air be exhausted out of two brass hemispherical cups, joined together only by a wet leather between them; if the diameter of each cup be $5\frac{1}{2}$ inches, it will require a force equal to 360 pounds to separate them: so strongly are they held together by the pressure of the atmosphere.



LECTURE VI.

On PNEUMATICS.

IF a leaden weight, of two or three pounds, be fixed to the end of a syringe, and held down till the piston be drawn up, and the air thereby lifted out of the syringe; the lead and syringe will then be forcibly pushed up on the piston, by the upward pressure of the external air.

If a large cork be exactly counterbalanced in air by a piece of lead, and covered with a close receiver, and the receiver be then exhausted; the cork will preponderate, and shew itself to be heavier than the lead.

If

If a lighted candle be placed under a close receiver that holds a gallon, the candle will burn a minute, and no longer: which shews, that a candle requires a gallon of fresh air every minute to feed its flame. When the flame goes out, the smoke will continue to ascend; but upon exhausting the receiver of air, the smoke will fall down to the bottom of the receiver: which shews, that smoke is not destitute of weight, but that it ascends in air because it is lighter than air.

If a little air be tied up in a bladder, and the bladder be covered with a close receiver; upon exhausting the air out of the receiver, the air confined in the bladder will expand so as to make the bladder appear full blown; but, on admitting the air into the receiver again, the bladder will be pressed into its former shrivelled state.

If the same bladder be put into a box, and have 16 or 20 pound weight of lead put upon it, and then be covered with a receiver, and the receiver exhausted of air, the air confined in the bladder will raise up the leaden weight by the force of its spring.

Most sorts of animals will die in the greatest agonies in an exhausted receiver.

If a tall receiver be exhausted of air, and joined by a pipe to a close air-light vessel about half full of water, the spring of the air in the vessel will force the water up into the receiver, and make a fountain therein.

By a machine called the *transferrer*, it is proved, that the receivers are held down on the pump by the weight of the air.

If a glass of warm beer be put under a receiver, and the receiver be exhausted; the beer will shew
all

all the appearance of boiling, as the air comes out of it by the force of its spring.

If about a cubic inch of dry wainscot be put into a glass of warm water, and covered with a receiver; on exhausting the receiver, the water will first seem to boil, as the air comes out of it: and then, an amazing quantity of air will come out of the wood and bubble in the water.

If a long glass tube, open at both ends, be cemented into the top of a jar, about half full of quicksilver, and covered with a tall receiver, and the receiver be exhausted; the spring of the air in the jar will force the quicksilver as high up in the tube as it rose formerly by the pressure of the air: which shews, that the spring of the air is just as strong as its pressure.

If a receiver be exhausted of air, and then the air be let into it through the flame of a candle, held to the end of a pipe which opens into the receiver through a brass cover; the receiver will be filled with burnt air. If then the cover be taken off, and an animal be put into the receiver, it will die: or, if a candle be put into the receiver, it will go out immediately.

LECTURE VII.

On ELECTRICITY.

THE electric fire or fluid comes from the earth to the *electrifying machine*, and is excited by the rubbing of a cushion on the glass globe. This fire circulates round the globe, to the sharp points of a metal bar, called the *conductor*; and will snap

snap against one's finger when held near the conductor.

The jars belonging to this machine are coated on the outside, and lined on the inside with tin-foil, to about two inches short of the top. A cork is put into each jar, and a brass wire is put down through the cork so as to touch the lining at bottom ; and a round knob is fixed to the top of each wire above its respective jar.

If such a jar be placed on a table, so as the knob may touch the conductor, and the globe be then turned round ; the electric fire will go off from the conductor, by the knob and wire, into the jar, and be condensed in its inside ; and the table will carry off as much fire from the outside as goes into the inside. So that, the inside of the jar will have more than its natural quantity of fire ; and the outside as much less.

Then, if a person holds a bended wire in his hand, and first touches the outside coating with the lower end of the wire, and then touches the knob with the other end ; a communication will be thereby formed between the coating and lining of the jar, and the fire will be discharged from the lining to the coating, with an audible noise : but the person who holds the wire will receive no shock.

If a jar be thus electrified, and a person takes hold of it by the coating with one hand, and touches the knob with a finger of the other, the fire will be discharged from the jar through his body ; and he will receive a shock, which will be felt in his arms and breast.

If a chain be hung to the coating of a jar, and the jar be electrified ; then, if ever so many persons stand so as to form a sort of a ring, and all but two join hands ; if the first person of the ring takes
hold

hold of the chain in his hand which joins not, and the last peason touches the conductor by a wire in the like hand ; the jar will be discharged through them all in an instant, and each person will receive a shock.

To confine the shock to any part of a person's body, as suppose from the elbow to the wrist, let one end of a chain be hung to the coating of the jar, and the other end be tied to the wrist by a silk cord or ribbon : then take another chain, and tie one end of it in the like manner to the elbow. This done, let the jar be charged, whilst another person holds the elbow chain about a foot from the loose end ; and then, if that person touches the conductor with the loose end of the chain, the jar will be discharged ; and the person to whom the chains are tied will receive a shock, from chain to chain : but the other person who holds the chain will receive nothing of the shock.

Electricity is found effectual for curing old sprains, rheumatic pains, and hard swellings : but, before any shocks are given, it would be proper to take many sparks of electric fire from the part affected ; as follows.

Let the affected person stand on a glass-footed stool, or on a board set upon four glass bottles ; and take hold of one end of a chain, the other end of which is hung on the conductor. Then if the globe of the machine be turned by the winch, the person will be electrified : and, if another person presents a knuckle of his finger to any part of the electrified person's body, the fire will snap from that part against his finger, every time he presents it. — A fresh scald with hot water, before it rises into a blister, is instantaneously relieved by taking sparks from it in this manner.

It is plainly shewn in miniature by this machine, that if a metal rod be fixed to a house, so as the upper end may be about two yards higher than the top of the chimney, and the lower end go down into the ground; if thunder breaks upon the house, it will not be hurt thereby; for the rod carries off all the lightning down into the earth. But, if the thunder breaks upon a weather-cock, it will run down to the foot of the iron spindle; and then, for want of a further metal conductor to carry it off, the house will be damaged.

If a Florence flask, or any other thin glass of that shape, be exhausted of air, and then held to the conductor to be electrified in a dark room; the electric fire will flash within the glass, and exactly resemble the *aurora borealis*.

Small models of compleat *water-mills*, *clocks*, and *orreries*, may be turned by a stream of the electric fluid from a pointed wire in the conductor.

All metals, and water, conduct the electric fire: but dry silk, hair, glass, resin, glue, and wax do not.

LECTURE VIII.

On the CENTRAL FORCES, and
Doctrines of the TIDES.

THE machine by which these are shewn, is called the *whirling table*.

Matter being inert and unactive, can neither put itself into motion, nor stop of itself after it has been put into motion in free space. The cause why all bodies stop that are put into motion near the earth, is the resistance of the air in which they move, and their own gravity, which makes them fall to the earth.

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When only one force acts upon a body, and puts it into motion, it can go no way but in the rectilinear direction in which that force impelled it. Therefore, when we see a body move in a curve of any kind, we must conclude that it is acted upon by two forces at least.

All bodies, moving in orbits, have a tendency to fly off from their orbits, and move in straight lines ; as is evident by a pebble whirled round one's hand in a sling. Therefore, to keep them in their orbits, some active power must be constantly drawing or impelling them toward the center of their orbits.

The planets are retained in their orbits by the power of gravity, and they are moved in their orbits by a projectile force impressed upon them by the Deity at the beginning.

The sun's attraction causes or constitutes the gravity of the planets : and, if that power alone acted upon them, it would bring them to the sun. If the projectile force alone acted upon the planets, it would carry them off in straight lines. But, by the proper adjustment of these two forces, the planets continue to go round the sun in their respective orbits.

The center of gravity between any two revolving bodies is a point round which they are in *equilibrio* : its distance from their centers is inversely as their quantities of matter.

When one body moves round another, both of them must move round their common center of gravity, as is plainly proved by experiment. Hence, the largest body in the solar system could not remain immoveable if any other body moved round it.

The quantity of matter in the sun is much greater than in all the planets put together. Therefore, the common center of gravity between the
sun

sun and planets is much nearer to the sun than to any planet in the system.

The common center of gravity between the sun and all the planets is at rest ; but the common center of gravity between any planet and its satellite is moveable ; and describes the orbit in which the planet itself would move if it had no satellite.

The common center of gravity between the earth and moon is 6000 miles from the earth's center. — As the earth and moon go round their common center of gravity every month, the earth's center describes a circle of 12000 miles diameter in that time ; and consequently, the earth is 12000 miles nearer the sun at the time of full moon than at the time of new moon.

All the parts of the earth have a tendency to fly off from this center of gravity, in proportion to their distance from it : therefore, the side of the earth which at any instant is turned away from the moon, has a greater centrifugal force, or tendency to fly off, than the earth's center has ; and the earth's center has a greater centrifugal force than the side of the earth has, which is then turned toward the moon.

At the earth's center, the moon's attraction balances the centrifugal force ; consequently, her attraction on the side next her is greater than the centrifugal force on that side, and less than the centrifugal force on the side farthest from her. As the moon's attraction on the side next her is greater than the centrifugal force there, her attraction causeth the tide to rise on that side.

As the centrifugal force on the side of the earth farthest from the moon is as much greater than her attraction, as her attraction on the side next to her is greater than the centrifugal force,

the tide must rise as high on that side of the earth, which is at any instant farthest from the moon, by the excess of the centrifugal force there, as it rises on the side which is then nearest the moon by the excess of her attraction; as is clearly proved to fight by an experiment.

A double velocity, in the same orbit, balances a quadruple power of gravity, or attraction, at the center of that orbit, as is manifest by experiment. Therefore, if the progressive velocity of any planet were twice as great as it now is, the sun's attraction would need to be four times as great, in order to retain the planet in its orbit.

The squares of the times, in which the planets go round the sun, are found by observation to be in the same proportion to one another as the cubes of their relative distances from the sun. Hence we find by experiment, that the sun's attraction diminishes in proportion as the squares of the distances from him increase. That is, at a double distance from the sun, his attraction is four times less; at a triple distance it is nine times less; at a quadruple distance it is sixteen times less; and so on, throughout the system.

The earth is of a spheroidal figure, flattened a little about its poles, and swelled out about the equator; so that its equatorial diameter is longer than its axis, as proved by the French observations. This demonstrates, that the earth turns round its axis; for, if it did not, the water would leave the equatoreal regions, and overflow the polar. The whirling sphere proves, that this figure of the earth arises from its motion on its axis.

LECTURE IX.

On the SOLAR SYSTEM.

THE *solar system* consists of the sun, six planets, ten moons, and the comets.

All the planets go round the sun, from west by south, to east; in orbits nearly circular, and but little inclined to each other.

The sun's diameter is about 890,000 English miles, and the earth's is only 7970. Hence, the sun is 1,389,200 times as big as the earth.

The six primary planets, are called *Mercury*, *Venus*, the *Earth*, *Mars*, *Jupiter*, and *Saturn*. The Earth has one moon, Jupiter four, and Saturn five, going round them.

The time in which any planet goes round the sun is the length of its year; and the time in which it turns round its axis, is the length of its day and night taken together.

Mercury goes round the sun in 87 days 23 hours; its diameter is 3000 English miles, its distance from the sun is 36,841,468 miles, and its hourly progressive motion in its orbit is 109,699 miles. The time of its diurnal motion, or length of its day and night, is unknown.

Venus goes round the sun in 224 days 17 hours: its diameter is 9330 miles, its distance from the sun is 68,891,486 miles, its hourly motion in its orbit is 80,295 miles, and it turns round its axis in 24 days and 8 hours.

The *Earth* goes round the sun in 365 days, 5 hours, 49 minutes: its diameter is 7970 miles, its distance from the sun is 95,173,000 miles, its
hourly

hourly motion in its orbit is 68,243 miles, and it turns round its axis in 24 hours.

The *Moon* goes round the earth, from change to change, in 29 days 12 hours 44 minutes 3 seconds; and turns round her axis in the same time. Her different phases prove that she shines by reflecting the sun's light, and not by any light of her own. Her diameter is 2170 miles, and her distance from the earth's center is 240,000. In respect of the earth, she moves 2290 miles every hour, in her orbit.

Mars goes round the sun in 1 year 321 days 17 hours: its diameter is 5400 miles, its distance from the sun is 145,014,148 miles; its hourly motion in its orbit is 55,287 miles; and it turns round its axis in 24 hours 40 minutes.

Jupiter goes round the sun in 11 years 314 days 18 hours: its diameter is 94,000 miles, its distance from the sun is 494,990,976; its hourly motion in its orbit is 29,083 miles, and it turns round its axis in 9 hours 56 minutes.

Jupiter's nearest moon goes round it in 1 day 18 hours 36 minutes; its next, or second moon, in 3 days 13 hours 15 minutes; its third moon, in 7 days 3 hours 59 minutes; and its fourth in 16 days 18 hours 30 minutes.

Saturn goes round the sun in 29 years 167 days: its diameter is 78,000 miles, exclusive of its ring; its distance from the sun is 907,956,130 miles, its hourly motion in its orbit is 22,102 miles, but the time of its rotation on its axis is unknown.

This planet has five moons, the nearest of which goes round it in 1 day 21 hours 19 minutes, the second in 2 days 17 hours 40 minutes, the third in 4 days 12 hours 25 minutes, the fourth in 15 days

22 hours 41 minutes, and the fifth in 79 days 7 hours 48 minutes.

If a body, projected from the sun, should continue to fly at the rate of 480 miles every hour (which is about the swiftness of a cannon ball) it would reach the orbit of *Mercury* in 8 years 276 days; of *Venus* in 16 years 136 days; of *the Earth* in 22 years 226 days; of *Mars* in 34 years 169 days; of *Jupiter* in 117 years 234 days; of *Saturn* in 215 years 287 days; and to the nearest of the *fixed stars* in about 8 millions of years.

From the time in which the planets are observed to go round the sun, and the universal power of gravity by which they are retained in their orbits, it is demonstrable, that if the earth's mean distance from the sun be divided into 100,000 equal parts, *Mercury's* mean distance from the sun must be equal to 38,710 of these parts; *Venus's* mean distance, 72,333; *Mars's* 152,369; *Jupiter's*, 520,096; and *Saturn's* 954,006.

Hence, if we know the real distance of any planet from the sun in miles, we may find the distances of all the rest by the above numbers. Now, by the transit of *Venus* in *June 1761*, the earth's mean distance from the sun was found to be 95,173,000 miles; and therefore, the mean distance of all the rest of the planets from the sun must be as above mentioned.

And, when the distance of any object is known, there are easy rules in geometry to know its real diameter, or bulk, from its apparent.

Now let us suppose that an *Orrery* is intended to be made, in which the sun and planets shall be represented in their proportional magnitudes, and the planets at their proper distances from the sun in
pro-

proportion to their magnitudes; the sun's diameter being 12 inches.

In this case, the diameter of *Mercury* would be $\frac{4.2}{1000}$ parts of an inch; the diameter of *Venus* $\frac{1.26}{1000}$ parts; the diameter of *the Earth* $\frac{1.07}{1000}$ parts; the *Moon's* diameter $\frac{2.9}{1000}$ parts; *Mars's* diameter $\frac{7.3}{1000}$ parts; *Jupiter's* diameter 1 inch and $\frac{2.67}{1000}$ parts; and *Saturn's* 1 inch and $\frac{5.2}{1000}$ parts.

Then, the true proportional distances of these planets from the sun would be as follows: *Mercury's* distance 41 feet; *Venus's* 77, *the Earth's* 107; the *Moon's* distance from the *Earth* $3\frac{2.3}{1000}$ inches; *Mars's* distance from the sun 163 feet; *Jupiter's*, 556; and *Saturn's*, 1020. — Consequently, there can be no such thing as having the sun and planets of their relative magnitudes, and at their proportionable distances, in an *Orrery*; even though the earth's diameter should be no more than the tenth part of an inch.

The sun's light diminishes in proportion as the square of the distance from him increases. At *Mercury*, the sun's light is almost seven times as great as it is at the Earth: at *Venus* almost twice as great: at *Mars* it is not quite half so great as at the Earth: at *Jupiter* it is but a 27th part so great as at the Earth; at *Saturn*, only a 90th part.

The earth by its annual motion round the sun, is 190 millions of miles nearer some of the stars at one time of the year than at another: and yet, the apparent magnitudes of these stars, and their angular distances from each other, are still the same. This proves, that if the earth were 190 millions of miles in diameter, it would appear no bigger than a mere dimensionless point, if viewed from any star; and consequently, that the distance of the stars from the earth is inconceivably great.

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At the distance of any star, all the planets in our system would be invisible; and the sun would appear no bigger than a common star does to us, consequently each star may be a sun to a system of planetary worlds, which by our best telescopes we cannot possibly discover.

The stars are vastly too remote from the sun, to be enlightened by him, so as to reflect light enough to make them visible. Hence it is plain that they shine by their own native and unborrowed lustre.

Those of the first magnitude cannot be less than the sun; otherwise they could not appear so big as they do. — But, as they are so big, and shine by their own light, 'tis plain they are suns.

'Tis probable that all the rest are as big, and only appear to be of different lesser magnitudes on account of their different distances.

The number of systems which would stand around our solar system, and next to it, is much less than the number of those which might stand next around them: and so on to infinity. And, the stars of the first magnitude are of a much less number than those of the second; those of the second much less in number than those of the third; and so on.

This circumstance makes it highly probable, that the stars which appear to be the biggest are suns to those systems of planets next around our system: those of the second magnitude, suns to those systems next beyond our neighbouring systems: and so on to the stars of the sixth magnitude, which are the smallest that the bare eye can perceive.

By means of the telescope, thousands of stars are seen, which are quite invisible to the bare eye. Those are of no manner of use to us, but we

cannot therefore conclude that they are altogether useless; and therefore we infer, that each star is a sun to a particular system of worlds.

The comets go round the sun in very excentric or long elliptical orbits, in the lower focus of all which, the sun is placed: and in their revolutions, they describe equal areas in equal times, as is shewn by a machine. The tail of each comet goes off from it toward the side of the heaven opposite to the sun, as seen from the comet.

LECTURE X.

On the SEASONS, *and* LONGITUDE.

THE *axis* of any planet is the line round which the planet turns: and the extremities of that line, at the planet's surface, are its *poles*.

The earth's motion on its axis is the cause of day and night. Its turning round every 24 hours produces the same effect as if the sun moved round it in that time.

The earth's axis inclines $23\frac{1}{2}$ degrees from a perpendicular to the ecliptic, in which it goes round the sun. Therefore, the earth's poles can never incline more than $23\frac{1}{2}$ degrees either toward or from the sun.

The obliquity of the earth's axis, and its constant parallelism throughout its whole annual course round the sun, are the causes of the different seasons, and the different lengths of days and nights.

The north pole of the earth's axis inclines more or less toward the sun, from the vernal equinox to the autumnal; and more or less from the sun, from the autumnal equinox to the vernal. In the former

former case, it is the summer half year in the northern hemisphere of the earth: and in the latter case, the winter half-year: and the contrary in the southern hemisphere of the earth. For, when the north pole inclines toward the sun, the south pole declines from him; and *vice versa*.

In the northern hemisphere, the vernal equinox (or equal day and night in the spring) is on the 20th of *March*; and the autumnal equinox (or equal day and night in autumn) is on the 23d of *September*. In the southern hemisphere, the contrary.

The earth goes round the sun every year in the ecliptic: and therefore, the sun appears to us to go round the ecliptic in that time. And in whatever point of the ecliptic the earth is, at any time, as seen from the sun, the sun's center will then appear to us to be in the opposite point of the ecliptic.

The equator is a great circle, all round the earth; and it divides the earth into two equal parts, called the northern and southern hemispheres. The north pole is the middle point of the northern hemisphere, and the south pole is the middle point of the southern.—The equinoctial circle in the heaven is directly over the earth's equator, and it divides the heaven into two equal parts, called the northern and southern hemispheres. The north and south poles of the heaven are directly over the north and south poles of the earth.

At the equinoxes, when the sun appears to be in the equinoctial circle, the earth's axis inclines neither toward him nor from him, but sideways to him. At the solstices, which are the middle days of summer and winter, the relative *pole* in-

clines $23\frac{1}{2}$ degrees toward or from the sun; and then he is $23\frac{1}{2}$ degrees from the equinoctial.

When the sun is in the equinoctial, he enlightens the earth just from pole to pole. — At all other times, he shines as many degrees round the pole which inclines toward him, as he is distant from the equinoctial toward that pole: and the opposite pole is then just as many degrees involved in darkness. — Thus, the sun shines round each pole, in its turn, for half a year together, and is just as long withdrawn from it: so that, at the poles of the earth, there is but one day and one night in the whole year.

The *northern tropic*, called the *Tropic of Cancer*, is a circle $23\frac{1}{2}$ degrees from the equator, on the north side; and the *southern tropic*, called the *Tropic of Capricorn*, is a circle $23\frac{1}{2}$ degrees from the equator, on the south side. The sun is in the *Tropic of Cancer* on the 20th of *June*, and in the *Tropic of Capricorn* on the 20th of *December*, as seen from the earth.

The *polar circles* are $23\frac{1}{2}$ degrees from the poles, all around them. When the sun is in the northern tropic, the whole space within the north polar circle is enlightened, and all within the south polar circle is in darkness; the contrary when the sun is in the southern tropic; as is plainly shewn by the *Orrery*.

The meridian of any place is a semicircle passing through that place, cutting the equator at right angles, and ending at the poles.

The earth's circumference is 360 degrees: and, as it turns round its axis in 24 hours, each meridian revolves 15 degrees in an hour: for 24 times 15 is 360.

Every place, whose meridian is 15, 30, 45, 60, or 75 degrees eastward (and so on, increasing by 15) from the meridian of any given place, has noon, and every other hour, one, two, three, four, or five hours (and so on in proportion) sooner than the given place has the like hour: if westward, so much later.

The longitude of any place is the number of degrees intercepted between its meridian and the meridian of any given place from which the longitude is reckoned: and is east or west, according as that place is east or west from the meridian of the given place.

The eclipses of *Jupiter's* moons afford a method for finding the longitude, according to the observed times of their happening, as seen from different parts of the earth. Thus, supposing such an eclipse to happen about six in the morning at *London*, and that it was seen at another place at four in the morning; the difference of time is two hours, which answers to 30 degrees. Consequently, the meridian of the place, where the eclipse was seen at four in the morning, is 30 degrees west from the meridian of *London*, where the same eclipse was seen at six in the morning.

These eclipses shew, that the motion of light is not instantaneous; but that it takes about 16 minutes to travel through a space equal to the diameter of the earth's orbit. For when *Jupiter* is nearly in conjunction with the sun, (that is, when the sun is nearly between the earth and *Jupiter*) these eclipses happen 16 minutes later than when *Jupiter* is opposite to the sun, which is, when the earth is between the sun and *Jupiter*. In the later case, the earth is nearer to *Jupiter* by the whole diameter of its orbit, (which

is 190,346,000 miles) than in the former. Therefore, as the sun is nearly in the center of the earth's orbit, and his mean distance from the earth is 95,173,600 miles; and, as light moves through a space equal to the diameter of the earth's orbit in 16 minutes, it moves from the sun to the earth in 8 minutes; which is with a swiftness 1,487,078 times as great as a cannon ball flies. — Hence it appears, that light moves 713,797,500 miles in an hour; 11,896,625 miles in a minute; and 198,277 miles in a second, which is 11848 times as fast as the earth moves in its annual orbit.

LECTURE XI.

On the MOTIONS *and* PHASES *of the* MOON.

THE moon turns round her axis in the time that she goes round her orbit, and therefore, she always keeps the same side toward the earth.

Her peridiocal revolution, or time of going round from any point of her orbit to the same point again, is 27 days 7 hours 43 minutes.

Her synodical revolution, or time from change to change, is 29 days 12 hours 44 minutes 3 seconds; which is the length of her day and night taken together: for, as seen from the sun, she turns only once round her axis in that time.

If the earth had no progressive (or annual) motion round the sun, the same point of the moon's orbit would always keep between the earth and the sun; and then, there would be no difference between

tween her periodical and synodical revolution ; for she would always change in the same point of her orbit.

But, as the earth is in continual motion round the sun, and the signs of the moon's orbit always keep parallel to the like signs of the fix'd ecliptic ; a different part of the moon's orbit will be every day between the earth and the sun from that point which was so on the day before : and therefore, the moon must move as many degrees more than round her orbit, between any change and the next following, as the earth has advanced in the ecliptic during that time ; which is $29\frac{1}{10}$ degrees.

As the moon goes quite round her orbit in 27 days 7 hours 43 minutes, and the earth goes round the sun but once a year ; the earth's axis has all the different positions to the moon in the time she goes round her orbit, that it has to the sun in a year.

The moon shines only by reflecting the sun's light : for, if she were a luminous body, she would always appear round, as the sun does.

A luminous body can enlighten only one half of an opaque globe at once ; and therefore, at any given moment, the sun can enlighten only one half of the moon.

When the moon is between the earth and the sun, she disappears ; because her un-enlightened side is then toward the earth. When she is opposite to the sun, she appears full : because her whole illuminated side is then toward the earth. When she is 90 degrees, or a quarter of a circle, distant from the sun, she appears half full ; because only one half of her enlightened side is then toward the earth.

The earth and moon are mutually moons to each other : but the earth gives thirteen times as much light to the moon as the moon gives to the earth ;
for,

for, the earth's surface is thirteen times as large as the moon's.

In considerable latitudes, the different *signs* of the ecliptic rise at very different angles with the horizon. In northern latitudes, the signs *pisces* and *aries* rise with the smallest angles; *virgo* and *libra* with the greatest. — Therefore,

When the moon is in *pisces* and *aries*, she rises nearly at the same hour for six or seven days together: but, when she is in *virgo* and *libra*, she rises so much later every day, as to differ eight hours in six or seven days.

In our winter, the moon is in *pisces* and *aries* in her first quarter, and then she rises about noon: but her rising at that time is not taken notice of, because the sun is above the horizon.

In spring, she is in *pisces* and *aries* about the time of her change: and as she is then invisible her rising cannot be perceived.

In summer, she is in *pisces* and *aries* about the time of her third quarter: and then as she does not rise till about midnight, her rising passes unobserved; especially as she is so much on the decrease.

In autumn, *pisces* and *aries* are opposite to the sun; and therefore, the moon is then full in them, and rises immediately after sun-set for several evenings together; which makes her rising very conspicuous, as it is so beneficial to the farmers, in affording them an immediate supply of light after sun-set, for reaping the fruits of the earth.

There is no harvest moon at the equator: as the latitude increases, it is the more remarkable; and most of all so at the polar circles.

LECTURE XII.

On ECLIPSES, &c.

ALL the planets and satellites are enlightened by the sun, and cast shadows toward that part of the heaven which is opposite the sun as seen from them.

If the sun and earth were equally big, the earth's shadow would be infinitely extended, and always of the same bulk; and would cover the planet *Mars* when it is opposite to the sun.

If the earth were bigger than the sun (and to us it seems to be the biggest body in the universe) its shadow would still be the bigger the farther it extended, and would cover *Jupiter* and all his moons when *Jupiter* was opposite to the sun.

If the sun be bigger than the earth, the shadow of the earth will be of a conical figure, and end in a point at a certain distance from the earth.

But the earth's shadow never reaches *Mars*, although that planet, when opposite to the sun, is not quite 50 millions of miles from the earth, which demonstrates that the sun is much bigger than the earth.

The moon is eclipsed when she falls into the earth's shadow. Therefore, she can never be eclipsed but when she is full; because that is the only time when she can be opposite to the sun. If she were a luminous body, she could not be darkened by the earth's shadow. For, a candle will suffer no diminution of its brightness by being placed in the shadow of a board, or globe, enlightened on the opposite side by another candle.

The sun is said to be eclipsed when the moon passeth directly between him and any part of the earth; which can only be at the time of new moon.

But, although the moon may then stop the sun's light from a small part of the earth, and *that* part must be darkened, because the moon's shadow covers it: yet as she does not take a single ray of light from the sun, strictly speaking, the sun is never eclipsed by the moon, any more than he is by the convexity of the earth when it hides him from our sight.—Notwithstanding, when the moon hides the whole or any part of the sun from our sight, we say, the sun is then eclipsed.

The moon's dark shadow can never cover a spot on the earth's surface of more than 180 miles diameter, at any time; and the shadow goes over that space in four minutes. Consequently, a total darkness, caused by a natural or regular eclipse of the sun, can never last above four minutes of time.

If the moon's orbit lay in the plane * of the ecliptic (in which the earth always moves) the sun would be eclipsed at the time of every new moon: and the moon would be eclipsed at the time of every full.

But, one half of the moon's orbit is on the north side of the plane of the ecliptic, and the other half is on the south side of it. Therefore the moon's orbit cuts the plane of the ecliptic only in two opposite points, which are called *the moon's nodes*. The angle which the moon's orbit makes with the ecliptic, is 5 degrees 18 minutes.

When the moon is any more than 12 degrees from either of her nodes at the time of being full, she passeth clear of the earth's shadow; and therefore she cannot be eclipsed at that time. But, when she

* If a circle be drawn upon a piece of flat paper, the paper may be called the plane of that circle.

she is within 12 degrees of either node at full, she is eclipsed; and if she be in either of the nodes when full, the eclipse will be central.

When the moon is any more than 18 degrees from either of her nodes at the time of change, she passeth either above or below the sun; and no part of the sun can be eclipsed by her at that time. But when she is within 18 degrees of either of her nodes at the time of change, she eclipseth the sun to some part of the earth. And if she be in the node, the eclipse will be central to that part of the earth's surface, which is in a right line between the sun's center and the earth's.

If the moon's nodes has no motion through the signs of the ecliptic, in whatever signs the sun and moon were eclipsed in any given year, they would be so in every year after. — But the eclipses fall so much back every year from the consequent toward the antecedent signs, as to prove that the nodes move backward $19\frac{1}{2}$ degrees every year. And therefore, in 18 years 225 days they go backward through the whole ecliptic.

From the time of the sun's being in conjunction with either of these nodes to the time of his being in conjunction with the other, is 173 days. If the nodes had no motion, the interval between these conjunctions would be $182\frac{1}{2}$ days, or a half year.

Always, in 18 years 11 days 7 hours 43 minutes there is a conjunction of the sun and moon with the same node; and therefore, in that time, there is a period or restitution of the same eclipses.

The darkness at our SAVIOUR's crucifixion could not possibly be occasioned by a natural or regular eclipse of the sun: for it was at the time of the Passover, and the Passover was always kept at the time of full moon.

He

He was crucified on the day next before the Jewish Sabbath, which being kept on our Saturday, the crucifixion was on a Friday : so that the Passover full moon in *that* year was on a Friday. — But it appears, by calculation, that there was only one Passover full moon on a Friday from the 20th to the 40th year of our Saviour, accounted from the vulgar æra of his birth : and *that* particular full moon was on the third day of April, in the 33d year of his age, reckoned from the æra of his birth.

The 33d year of CHRIST was the fourth year of the 202d Olympiad. And *Phlegon*, a heathen writer, tells us, that “ in the fourth year of the “ 202d Olympiad, there was the greatest eclipse “ of the sun that ever was known ; for the day “ was turned into night for three hours, and the “ stars in the heaven was seen.”

Ptolemy's cannon fixes the year, in which the commandment was given to *Ezra* by *Artaxerxes Longimanus*, to restore and build *Jerusalem*, to the 457th year before the vulgar æra of CHRIST's birth : and, according to *Daniel's* prophecies, the death of CHRIST was to be at the end of 70 weeks (of years) or 490 years after the time when that commandment was given.

And 33 years being added to 457, makes up the whole 490 ; that is, from the year of the commandment to the 33d year of CHRIST ; which we prove by astronomy to have been the year of his death : concerning which, we have the testimony of a heathen writer ; who, not being an astronomer, mistook a supernatural darkness for an eclipse of the sun.



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